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# THERMODYNAMICS ONE



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# *Preface*

Fall 2020 projects are described inside.



# 1

## *Stadium Roof*

Estimate the energy requirements for the HVAC (heating, ventilation, and air-conditioning) system serving a very large indoor stadium. I often described the project in terms of adding a roof to Bryant-Denny Stadium, but any stadium or similar structure would suffice. Consider the Superdome in New Orleans: its interior volume is approximately 3,500,000 m<sup>3</sup>. Be sure to choose a structure that does not exist. For example, imagining Bryant-Denny with a roof is a great project, whereas calculating the energy needs of the Superdome is not.

### *1.1 Human Comfort*

Humans indoors find comfort in relatively narrow ranges of temperature and relative humidity, depending on season. Achieving and maintaining a comfortable environment can be an expensive undertaking. For easy proof, look at August and February utility bills. Expenditures related to HVAC make up a very large portion of worldwide energy consumption. Efficiently maintaining the proper temperature is challenging; controlling the humidity can be energy-intensive. When the humidity is too low, people suffer from cracked skin, nosebleeds, allergy attacks, and general discomfort. High humidity promotes the growth of mold, which can lead to very serious chronic health problems, even death.

### *1.2 Project Details*

1. Establish your stadium geometry.
2. Account for energy sources and sinks:
  - a. People generating heat and releasing water vapor
  - b. Heat transfer through the roof, especially solar irradiation
  - c. Heat transfer through the walls. Use a reasonable facsimile to represent the walls. With a stadium that is relatively open

underneath (like BDS), the walls would be the concrete structure immediately under the seats. From Figure 1.1, it is easy to see that a sunken stadium like Michigan’s “Big House” or one with earthen walls, like those of the Yale Bowl, will have much different heat transfer characteristics than a stadium that is completely above grade.

- d. Keep in mind, an HVAC systems take in air, condition it, then return it to the occupied space. It takes energy to motivate air to move. Moreover, people generally do not like feeling moving air when they are indoors.

### 1.3 *Calculations*

1. Develop worst-case scenarios for heating and cooling your stadium, eg, August and February days and nights, and calculate required rates of energy transfer. Outdoor conditions can be found in an almanac or NOAA climactic data.
2. Calculate the power required for an air conditioner or heat pump to meet cooling demands. Determine the cost of said power.
3. Calculate power requirements for a heat pump to satisfy heating demands. Compare heat pump power and cost to those of heating by natural gas and heating by pure electric Joule heating.
4. Calculate the time it takes your HVAC system to reach comfortable conditions, assuming the indoor environment is the same as outdoor ambient conditions.

### 1.4 *Report*

*coming soon*

### 1.5 *Resources*

*coming soon*





Figure 1.1: Michigan Stadium (L),  
and the Yale Bowl



## 2

# *Quick Chill*

### **N05-164, US Navy Request for Proposals**

#### *Technology areas*

Materials/Processes, Human Systems

#### *Objective*

Develop an energy efficient, rugged, shipboard capability to quickly chill a canned beverage product (e.g., soda pop, or “soft drink”) to help eliminate the requirement for operating traditional vending machines at sea.

### *2.1 Project Summary*

For the primary customer on a ship (male, 22 years old), a key Quality of Life (QOL) element as documented by customer surveys is the ability to obtain a cold soft drink from a vending machine. That the per capita consumption of the commodity is almost double the U.S. per capita rate (52 gal a year) testifies to the popularity and desirability of this service. To satisfy this demand, the Navy as part of its QOL programs provides soft drink vending machines on ships. The design of the ship (storerooms separated from selling locations) coupled with the lack of transportation aids and the requirement to have up to 14 machines on larger ships has driven large platforms to devote up to six (6) man-years of effort to keep the machines filled. As the cost of manpower has increased, the need to find alternatives to provide this key QOL product has grown.

The desire is to develop a device capable of chilling a soft drink within 10 seconds, which is estimated to be the upper limit, or customer wait time tolerance, for the beverage consumer. The militarized version of the device needs to be compact and reliable, with little or no in-service maintenance requirements. Such a device, when distributed throughout the shipboard environment, could provide the following benefits:

1. Eliminate, or minimize, shipboard requirements for environmentally threatening use of refrigerants (o-zone deleting substances)
2. Potentially remove all labor requirements involved in the operation of vending machines.
3. Removing the requirement for the product to be chilled at the point-of-sale, enabling more purchasing and storage flexibility to both the retailer (Ship's Store) and the consumer (sailor)

## 2.2 *Background*

The rapid chilling of bulk food products (e.g., dairy, fruits & vegetables) and especially solid food (e.g., carcass meat, fresh fish) is a long sought-after industry endeavor that has posted modest advances, with futuristic sights on a capability akin to a “reverse microwave”. Restricted by the same heat transfer principles, the objective to rapidly chill a packaged consumer beverage can proceed towards a similar outcome when, and if, technology pushes past the decades-old capability of the vending machine. Rapid chill, with chill-on-demand service, is an evolutionary step away from the trappings of 20th century vending technology.

Consumer appeal for a chill on demand capability is demonstrated in sales of counter-top, household products promising to chill a bottle of wine in six minutes, or a canned beverage in one minute. However, products currently known to be available are extremely limited in applicability, essentially relegated to home use given the need to add both water and ice to the device. Other chill-on-demand technologies include a self-refrigerating beverage can promising to cool 30 °F in three minutes.

While these two examples of technological applications demonstrate the variability in potential approaches for obtaining the desired objective, neither is close to the required shipboard solution (ease-of-use, adequate chilling within 10 seconds). In addition, before any organization will embrace a modern technology, it will determine if the cost of new technology is “affordable” either in acquisition cost or “tradeoff” cost of providing the current service. The shipboard technical requirement exceeds any technology known to be available in the marketplace, and therefore presents unusually high technical risk. For these reasons, some leeway may be accommodated for the desired objective considering the proposed study approaches received.

## 2.3 *Project*

Investigate alternative technologies/approaches to rapidly chill aluminum can packaged soft drinks/beverages. Evaluate and document

alternatives and a developmental approach for one or more candidate devices.

A promising method is to have a chamber (or chambers) submerged in the drink. In the chamber is a fluid under pressure that will vaporize at atmospheric pressure and normal room temperature. When the chambers are opened, the fluid vaporizes. The Second Law demands the vaporization. The First Law demands the energy required for the phase change to take place. That energy is taken from anything in contact; it cannot be avoided. In this case, the energy is stolen from the soft drink, cooling it. *Yes, this is what causes an aerosol can to get cold when sprayed.*

Other methods abound, but I'm less familiar with how they work. You're free to propose anything feasible. I'm willing to help you sort out your ideas as well.

1. Develop a device capable of chilling a soft drink within 10 seconds.
2. Assume the soft drink is 12 fl. oz. of water.
3. Assume the soft drink is initially 30,°C and must be chilled to 1,°C.
4. Use any of the substances tabulated in any textbook, ASHRAE manuals, NIST, etc.
5. Check for toxicity. I'm no advertising expert, but killing customers seems like it may potentially harm sales.



### 3

## *Rocket Cryogenic Storage*

Storing Cryogenic liquids is a challenging endeavor. Cryogenic liquids have boiling points that are far below ambient temperature. When storing them, a major challenge is reducing boil-off. The cryogen is under saturation conditions, so any heat transfer into the tank increases the vapor fraction of the cryogen. This is a serious concern for applications that require liquid cryogen (as opposed to very cold gas).

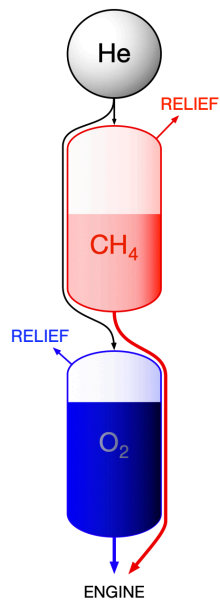


Figure 3.1: Simple depiction of a rocket fuel system

If the cryogen is stored in a rigid tank, pressure increases until the tank eventually ruptures. A mechanically robust tank is an option, but a tank robust enough to survive the pressure increase would be extremely heavy. Normally, cryogenic storage tanks (dewars) are vented, but that means lost cryogen.

You are charged with designing the fuel system for a rocket fueled by liquid methane (LMG), with liquid oxygen (LOX) oxidizer. We've

already determined how much fuel and oxidizer are required to complete the mission. Your major concern is the loss of LMG and LOX while the rocket sits on the pad. You will be launching from the New Mexico desert in mid-June, and the rocket may sit on the pad for up to 2 hours after fueling. Because you're so good at thermodynamics, you know you have several options at your disposal:

1. Increase tank pressure.
2. Insulate the tanks.
3. Load extra cryogenics and vent the excess.
4. Other clever ideas I didn't realize.

### *3.1 Project*

Develop a calculator that will compute optimum tank dimensions given user-defined constraints and requirements.

### *3.2 Possible Inputs*

1. Required liftoff masses of both fuel and oxidizer, or either fuel or oxidizer.
2. Maximum diameter, length, volume, or mass of each tank.
3. Other parameters you find important.

### *3.3 Outputs*

1. Dimensions of both tanks.
2. Specify initial masses of LOX and LMG to be loaded into each tank. This is the amount before any boiloff begins.
3. Specify operating pressure of each tank.
4. Specify the insulation type and its thickness.
5. Alert user if they have specified a set of requirements that cannot be met.

### *3.4 Constraints, Requirements, Complications*

1. It's a rocket. Low weight is holy and just.
2. Consider the wisdom of venting a lot of fuel and oxidizer in the same general area.
3. Heat transfer

### *3.5 Bonus*

Account for the mechanical strength of the tank material in your calculations.



### 3.6 Resources

1. You will need property data beyond what is in your textbook. Feel free to use other texts, ASHRAE Handbooks, NASA (McBride et al., 2002), (noa, b) and DOD (noa, a) libraries, etc. Mathematica (UA has a site license) has a very nice thermodynamic properties function. The NIST (Linstrom and Mallard, 2019) Chemistry Web-Book may be a good option. Find it at [webbook.nist.gov](http://webbook.nist.gov). Cool-Prop (Bell et al., 2014) is a popular open-source thermodynamic property calculator that works with platforms like Python, Julia, Python, Excel, MATLAB, Maple, and at least a dozen others.
2. Heat transfer into a liquid is always higher than heat transfer to a vapor. Boiling liquids provide some of the highest heat transfer rates possible. I can point you to dozens of great sources for information about the heat transfer of fluids changing phase.



## 4

# *Home Energy Audit*

As energy conservation efforts have intensified among the Transportation, Industrial, and Business sectors, the Residential sector has emerged as an increasingly important opportunity to reduce our energy footprint. HVAC (heating, ventilation, and air conditioning), water heaters, and clothes dryers require enormous amounts of energy. Energy traipses through doors and windows as if it carries a perpetual red carpet invitation.

### *4.1 Twenty-one questions*

During winter, do you stay away from windows because it's cold over there? Does it seem like the cold is tumbling into your room near the windows? Do your windows ever fog up or collect condensation during the summer? Do you know anyone that has performed a home energy audit? Have you? Without looking, what information appears on an Energy Star EnergyGuide label? label? Would you allow your power utility to cycle your HVAC system on/off during periods of peak power usage in exchange for discount pricing?

### *4.2 Energy Guides and Audits*

Energy savings guides are everywhere. They are published by government energy agencies, environmental interest groups, utilities, home builders and appliance companies, and organizations that perform professional energy audits, of course.

...the only things on the 'net more prevalent than energy guides are cat videos...

— marcucius, ca 2020

Here are some examples of guides and labels from around the world: Canada (guide, labels), Hong Kong, European Union (labeling, consumer guide), Barbados, and an infographic from the US Department of Energy

### 4.3 *The Project: Home Energy Audit*

Home energy audits tend to come in only two flavors: professional-caliber audits that require specialized instrumentation and consumer-grade versions that have lots of pretty graphics (perhaps your bias meter just started beeping wildly). Let's be clear: they get the job done, but pass little of the underlying science to the user. Moreover, they have little appeal to people that aren't already wanting to perform an energy audit.

Your mission is to create a more balanced home energy audit.

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- has thermo
- dual emphasis on cost and environment
- for parent and child, perhaps distributed as class project
  - have child do some plotting for the child. maybe \$\$ vs temp/season vs other relevant factors
  - have some instant activities
    - reading meters with appliances on/off, etc
    - ht trans through windows/door
  - kid makes conclusions, maybe predicts savings
- has thermo
  - CLARIFY, not SIMPLIFY. use natgeo example
  - maybe a kit with inexpensive sensors, or uses one of those temperature/hygrometers that goes in rept.
- output
  - maybe a guide
  - maybe an full featured app
  - maybe an app that uses a phone/pad/laptop's sensors for time, temp, etc
  - you could storyboard an app, and implement the calculations in another environment (preferably not s

5

## *Stirling Engine*

Build a working Stirling engine powered by a candle.



6

## *Waste-to-Energy*

*under construction*

Kill a flock of birds with one rock and a good throw.





*7*

## *Waste Heat Recovery*

*under construction*



# 8

## *Writing a **Great** Technical Report*

*under construction*

### *8.1 Pain, peril, promise*

1. Abstract/Summary
2. Pain
3. Attempted solutions
4. Promise
5. Work
6. Results
7. Well...?
8. Now what?



## 9

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